

HAT STIFFENED PLATES FOR SHIP BUILDING

MANOJ G THARIAN¹ & NANDAKUMAR C G²

¹Assistant Professor, Mechanical Engineering Dept., Rajagiri School of Engineering & Technology, Kochi, Kerala, India

²Associate Professor, Dept. of Ship Technology, CUSAT, Kochi, Kerala, India

ABSTRACT

The key interest in ship building is to design a ship having minimum weight and maximum strength. Usage of open sections like Flat bar, Angle bar, Holland Profile and Tee bar are common in ship structure. The stiffeners of closed section offer numerous advantages as much from the structural as from the economic point of view. Hat Stiffened Plate has a number of closed profile stiffeners provided along dominant direction. A representative unit cell of Hat Stiffened Plate has been selected and numerical investigations using finite element software ANSYS have been carried out to quantify the structural advantages of hat shaped stiffeners over the commonly used open section stiffeners like flat bar, angle and tee sections. Hat stiffeners can very effectively be used in the design of lighter ships.

KEYWORDS: Stiffeners of Closed Section, Hat Stiffened Plate, Open Section Stiffeners, Structural Response, Finite Element Analysis

INTRODUCTION

The key elements of a ship hull structure are bottom and side shell plating which serve as a watertight envelope of the ship as well as the principal strength member, deck plating and transverse bulkheads which contribute substantially to the strength and may also serve as liquid tight boundaries of internal compartments, fore end, aft end and superstructure as shown in Figure 1. Ship structure in general can be considered as a three dimensional frame work of stiffened plates, constituted by deck, side shells, bottom shell and bulkheads.

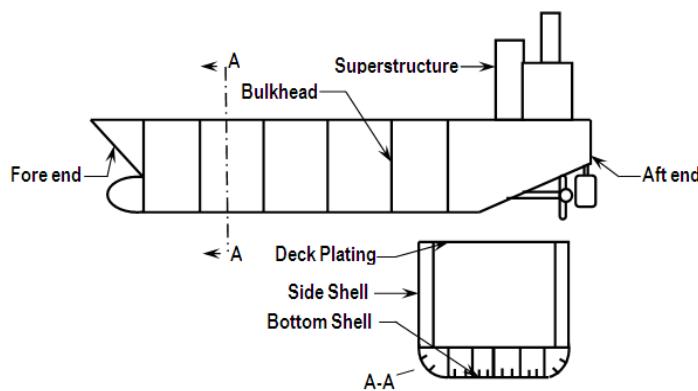


Figure 1: Key Elements of a Ship Structure

Ship structure at sea is subjected to static and dynamic forces of large magnitude. The ship structure is subjected to static forces, due to the water surrounding the ship, due to the weight of the cargo and due to the weight of the structure itself. The effect of these static forces is to cause a transverse distortion. For a ship floating in still water, although the total buoyant force is equal to the weight of the ship, due to the unalike distribution of the weight and the buoyancy along the

length of the ship, it is subjected to shear force and bending moment. The bending moment causes the ship to bend in a longitudinal vertical plane like a beam. When the ship is moving amongst waves, distribution of weight remains unchanged, but the distribution of buoyancy along the length is altered. This modification in the distribution of buoyancy causes a change in the shearing force and bending moment acting upon the ship in still water. The waves running against the hull and the wind blowing against the hull exerts dynamic forces on the hull. Occasionally the motion of the ship may be sufficiently large to cause it to leave the water altogether and large dynamic forces are generated when it makes contact with the water again. This occurs especially near the fore end of the ship and is often referred to as slamming. Other forces exerted on the ship structure are hull drag, the force of the propeller, water driven up against the bow, force exerted by moving cargo etc. Since the ship remains intact, these forces tend to distort the vessel.

In a ship structure, the portion of the decks abreast the line of openings, the side shell plating, inner and outer bottom shell plating will contribute to the longitudinal strength and resist the longitudinal bending. The deck, side shell, inner and bottom shells together forms a box girder of very large dimensions in relation to the plate thickness. Unless the plating is stiffened, it would be inept to withstand the compressive loading due to the bending. In earlier days the stiffening was provided by fitting transverse rings of material spaced from 2ft to 3ft apart throughout the length of the ship and it is usually called a transversely framed ship. Modern ships adopt a longitudinal system of framing for the decks and bottom as well as for the sides of the ship.

The longitudinals attached effectively to the plating contribute to the general longitudinal strength of the ship and will withstand the cargo and water pressure loads. In order to reduce their scantlings they are supported at locations other than bulkheads by deep transverse beams, in the decks and by providing transverse floors in the bottom. The transverse bulkheads increase the transverse strength of the ship and have the same effect as the ends of a box. In a ship structure most of the lateral load act initially on the plating. Through the action of plate bending, the plating transmits the lateral load to nearby stiffeners. The stiffeners in turn transmit the load to transverse beams and longitudinal girders. The key interest in ship building is to design a structure having minimum weight and maximum strength. Ships which are built too strong are heavy, slow, and cost extra money to build and operate since they weigh more, whilst ships which are built too weak suffer from minor hull damage and in some extreme cases catastrophic failure and sinking. So there has always been a constant strive among ship designers to design strong and lighter ships.

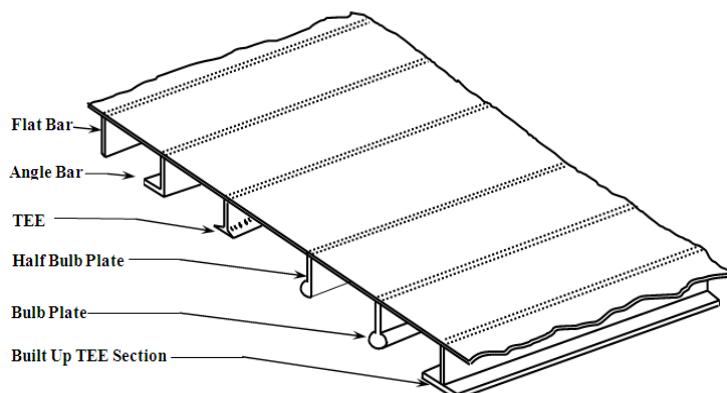


Figure 2: Commonly used Open Section Stiffeners in Ship Building

A stiffened plate or panel is an assembly of stiffener and plate where the stiffeners are welded on to the plate. The stiffeners are usually rolled steel sections. Usage of open sections like Flat Bar, Angle, Holland Profile (bulb plate) and Tee

as shown in Figure 2 are common in ship structure. In the case of a flat bar stiffener, a simple flat bar is edge welded to the supported plating. Inverted unequal leg angles, with the edge of the long leg welded to the plating, are relatively cheap stiffeners through the available range of sizes. Large angle size may be obtained by cutting one flange from a channel section. Bulb plates are frequently used in ships built outside the USA. If tested to failure, T bars may be expected to resist bending better than inverted angles because of their symmetrical flange.

The advantages of closed section stiffeners over the open section stiffeners both in the strength and economic point of view have been brought out by Dubas (1976). Closed section stiffeners provide a higher bending stiffness and thus allow a greater spacing of the stiffeners. The high Saint Venant torsional rigidity of closed section stiffeners enhances the ultimate strength of the stiffened plate. Moreover the geometrical configuration alone allows a greater spacing between the stiffeners due to their own width. The connection with the plate requires only two fillet welds which are no more than what is required for a single open section stiffener.

Thus closed section stiffeners have definite advantages over open section stiffeners especially with regard to the torsional rigidity and weight strength ratio. The enclosed space between the stiffener and the plate in the case of closed section stiffeners can effectively be utilized as a duct for the passage of cables.

However the cost of labor employed on the fabrication of these sections by the process of cold forming necessary for obtaining the required shape of section is slightly high as compared to open sections (Dubas 1976). Also closed sections provide restricted access to a portion of the plate which can affect the inspection for corrosion. In spite of this, closed sections stiffeners can be successfully employed in certain parts of a ship structure.

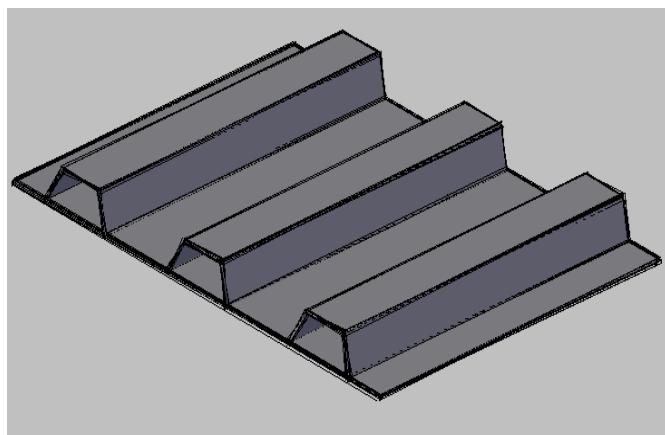


Figure 3: Schematics of a Typical Hat Stiffened Plate with Three Stiffeners

Trapezoidal or Hat Shaped Stiffener is a typical closed section stiffener of wide application in land based constructions but is not common in marine applications. Trough shaped steel sections having the same shape as hat stiffeners, which may or may not be filled with bitumastic composition, are used as fenders on small ships (D'Arcangelo, 1969). Hat stiffened plate have a number of closed profile stiffeners provided along the dominant direction as shown in Figure 3.

Hat stiffeners are usually formed sections. In the case of steel structures the hat stiffeners are either welded or riveted to the plate, if riveted flanges are added. For composite structures the hat stiffeners are bonded to the plate and

flanges are provided for the stiffeners. The weight strength efficiency of hat stiffened plate has made it a choice for structural engineers in their attempt to design light steel deck structures for high speed vessels (Jia and Ulfvarson, 2004).

A definite need has been felt to carry out numerical investigations to quantify the structural advantages of hat shaped stiffeners over the commonly used open section stiffeners. The structural response of plates stiffened with hat shaped stiffeners and with open section stiffeners like flat bar, angle and Tee sections, to lateral loading, inplane loading and torsion loading has been estimated using finite element software ANSYS and has been presented in this paper.

HAT STIFFENED PLATE

Structural Characteristics

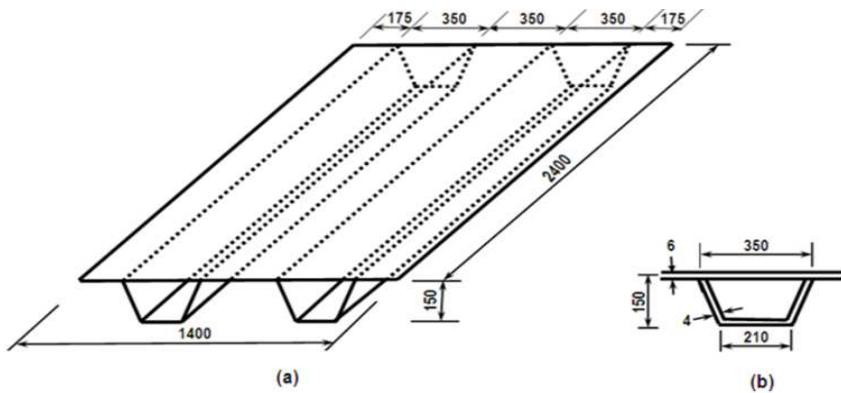


Figure 4: (a) Illustrations of Geometry and Dimensions of HSP having Two Stiffeners

(b) The Principal Dimensions of the Hat Stiffener

A section of the stiffened plate between two successive transverse deck beams of a conceptual lightweight ship deck on a pure car truck carrier vessel proposed by Jia and Ulfvarson (2004) and having a span of 2.4 m has been selected for the study. Geometry and dimensions of hat stiffened plate having two stiffeners and the principal dimensions of the hat stiffeners have been shown in Figure 4.

Material Properties

The structure is made with EHS690 steel. The Poisson's ratio of the material is 0.3, the modulus of elasticity is 210 GPa, the density is 7800 kg/m³, and the yield stress is 690 MPa.

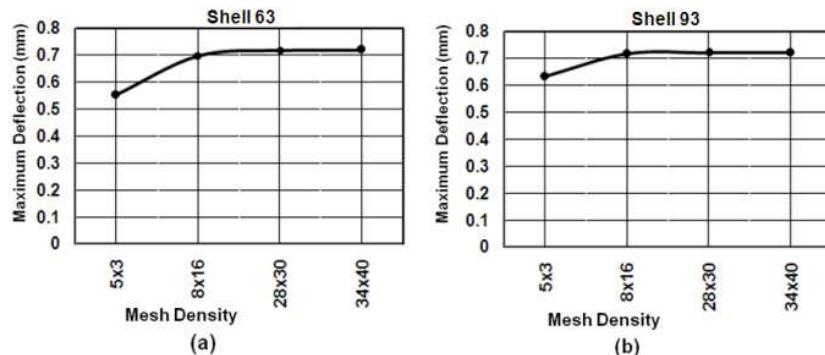
Convergence Study

The structure has been modeled and analyzed using the finite element software ANSYS 12. Thin shell elements, shell 63 and shell 93 having six degrees of freedom per node have been used to model the stiffener and the plate. The mesh density has been selected based on a convergence study carried out for a hat stiffened plate having two stiffeners as shown in Figure 4, using shell 63 which is a 4 noded element and shell 93 which is an 8 noded element. Specifically inplane mesh densities 5x8, 8x16, 28x30 and 34x40 have been chosen for the convergence study. Simply supported boundary condition on all four edges and a uniformly distributed lateral pressure of 10 kPa has been applied on the hat stiffened plate. The maximum deflection has been found out for various mesh densities. The results of the study carried out using shell 63 and shell 93 elements have been given in Table 1.

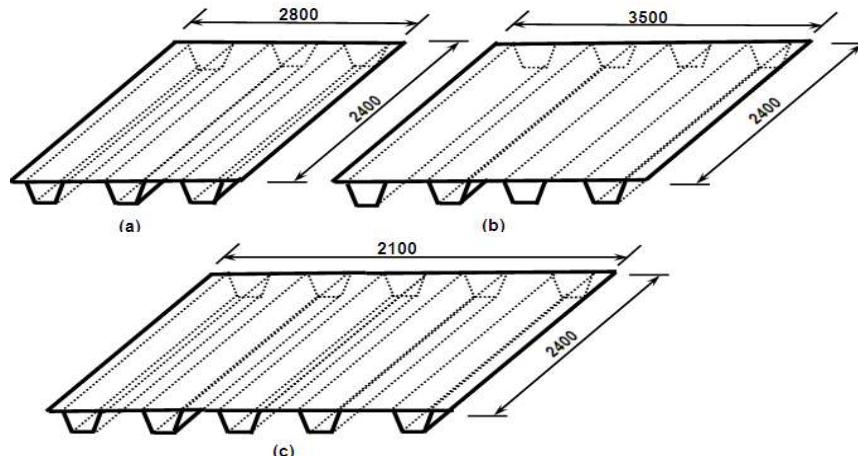
Table 1: Mesh Sensitivity of HSP Modeled using Shell 63 and Shell 93 Elements

Mesh Density:	Maximum Deflection (mm)			
	5x8	8x16	28x30	34x40
Shell 63 (4 Noded Element)	0.5516	0.6980	0.7065	0.7198
Shell 93 (8 Noded Element)	0.6308	0.7178	0.7207	0.7214

Plots of maximum deflection for various mesh densities has been made for shell 63 and shell 93 element and are shown in Figure 5. Shell 93 element show convergence for a mesh density of 28 x 30 and an aspect ratio of 1.8. Shell 93 has been adopted for further investigations.

**Figure 5: Plot of Maximum Deflection Versus Mesh Density (a) for Shell 63 Element (b) for Shell 93 Element**

Selection of Unit Cell



**Figure 6: Illustrations of Geometry and Dimensions of hat Stiffened Plates having (a) Three Stiffeners
(b) Four Stiffeners (c) Five Stiffeners**

The deck plate of ship or any other application of hat stiffened plate may be a structural member measuring a few meters. For the numerical investigations of such structural components, it will be convenient to have a representative unit cell which is a miniature of the original structure.

A representative unit cell of the hat stiffened plate has been selected based on a linear static analysis carried out for hat stiffened plate panels having two, three, four and five stiffeners. Geometry of these representative unit cells have

been given in Figures 4 and 6. These plates have been modeled using shell 93 elements. Simply supported boundary conditions are prescribed on edges perpendicular to the stiffeners and continuous boundary conditions have been imposed on edges parallel to the stiffeners. A uniformly distributed lateral pressure of 10 kPa has been applied on the hat stiffened plate.

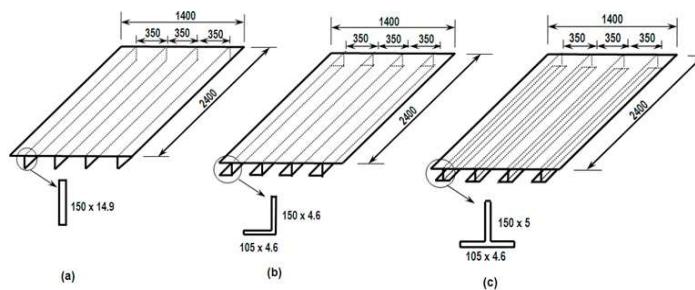
Comparison of maximum deflection and maximum inplane stress at the centre of hat stiffened plate having three, four and five stiffeners with that obtained for hat stiffened plate having two stiffeners has been presented in table 2. Since the maximum deflection has been the same and the variation in stress has been less than 4%, hat stiffened plate with two stiffeners as shown in Figure 4 has been selected as the representative unit cell.

Table 2: Comparison of Maximum Deflection and Maximum Inplane Stress at the Centre Obtained for Hat Stiffened Plates having Two Stiffeners, Three Stiffeners, Four Stiffeners and Five Stiffeners

No. of Stiffeners:	Two Stiffeners	Three Stiffeners		Four Stiffeners		Five Stiffeners	
			Percentage Variation		Percentage Variation		Percentage Variation
Maximum Deflection (mm) :	0.7093	0.7093	0	0.7093	0	0.7093	0
Maximum Inplane Stress (M Pa.) :	10.09	9.70	3.87	10.09	0	9.70	3.87

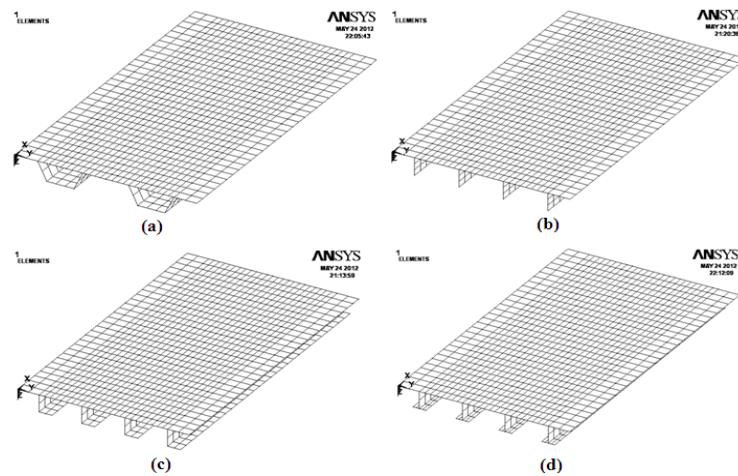
STRENGTH OF STIFFENERS COMMONLY USED IN SHIPBUILDING

The structural response of hat stiffened plate has been compared with that of commonly used open section stiffeners in ship building, viz., flat bar, angle bar and tee bar. The equivalent unit cell of open section stiffeners are arrived at based on the equivalent section modulus concept. The scantling of the stiffeners are calculated such that the plate dimensions of hat stiffened plate and open section stiffened plates are same and both have equal section modulus. The dimensions of the equivalent representative unit cells of flat bar, angle bar and tee bar stiffened plates are shown in Figure 7.



**Figure 7: Illustrations of Geometry and Dimensions of Stiffened Plates Stiffened with (a) Flat Bar
(b) Angle Bar and (c) Tee Bar**

STRUCTURAL RESPONSE



**Figure 8: Finite Element Models of Plate Stiffened with (a) Hat Stiffener (b) Flat Bar
(c) Angle Bar and (d) Tee Bar**

The structural response to lateral loading, inplane loading and torsion loading of representative unit cell of hat stiffened plate and its equivalent open section stiffened plates have been estimated and compared. The analysis has been carried out using ANSYS and finite element models of representative unit cells of plates stiffened with hat stiffener, flat bar, angle bar and tee bar have been shown in Figure 8.

Lateral Loading

In a ship structure the stiffened plates are mainly subjected lateral loads i.e., loads normal to the plane of the plate. Hydrostatic pressure acting on the bottom and side shells of the plate, cargo distributed on the deck etc are examples for lateral loads acting on stiffened plates in the case of a ship structure. Simply supported boundary condition on all four edges and a lateral pressure of 10 kPa has been applied in each of the four cases. Linear static finite element analysis has been carried out using ANSYS and a comparison of maximum deflection and maximum principal stress has been made and presented in table 3. From the table it has been seen that for same section modulus the plate stiffened with flat stiffener is 36% heavier as compared to hat stiffened plate. The maximum deflection and the maximum principal stress for plate stiffened with angle stiffener have been very high as compared to hat stiffened plate. The variation in maximum deflection and maximum principal stress for tee stiffener has been found to be less than 4% as compared to that of hat stiffened plate. Plate stiffened with tee bars exhibits comparable weight strength efficiency with that of hat stiffened plate for lateral loading.

Table 3: Comparison of Maximum Deflection and Maximum Principal Stress for the Plates Stiffened with Four Different Types of Stiffeners and Subjected to Lateral Load

Sl No	Stiffener Shape	Weight Ratio	Section Modulus	Max Deflection	Max. Deflection Ratio	Max. Principal Stress	Max. Principal Stress Ratio
			cm ³	mm		N/mm ²	
1	Hat	1.00	381.94	0.7207	1.00	26.50	1.00
2	Bar	1.36	380.4	0.6348	0.88	25.37	0.96
3	Angle	1.01	382.4	1.3864	1.92	89.07	3.36
4	Tee	1.03	382.4	0.7061	0.98	27.60	1.04

Inplane Loading

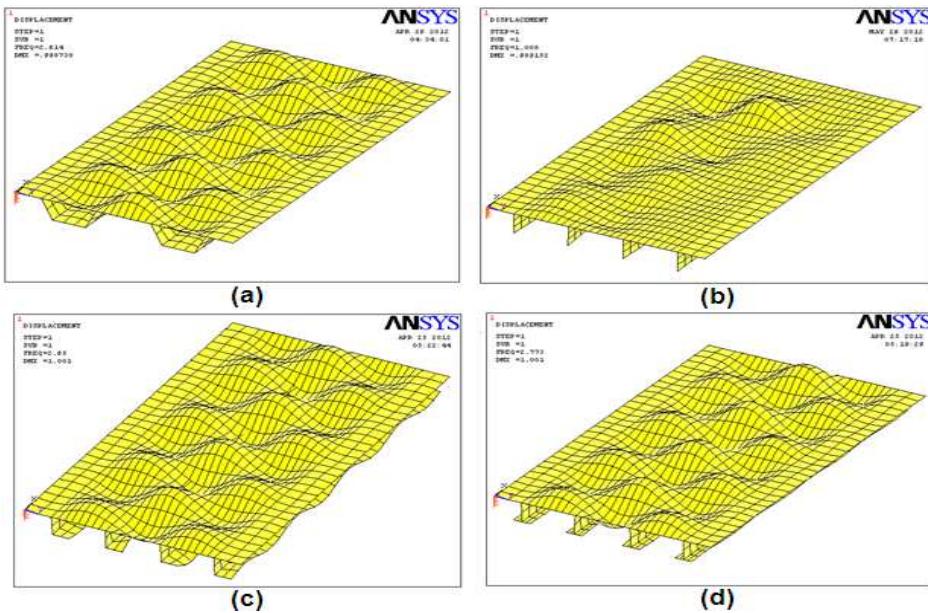


Figure 9: First Buckling Mode for Plate Stiffened with (a) Hat Stiffener, (b) Flat Bar, (c) Angle Bar and (d) Tee Bar

The top deck of ship's hull is subjected to bending compressive stress due to sagging bending moments and it is prone to buckling failure. The buckling mode for a stiffened plate depends on the relative geometric proportions of the plate and stiffener elements (Bediari, 1997). For light stiffening, the plate buckles together with the stiffener giving rise to failure in overall buckling mode.

If the stiffener is rigid in flexure and weak in torsion, buckling occurs in a local mode. The stiffeners in this case divide the plate into several sub-panels with longitudinal edges almost rotationally free. If the stiffener is both flexurally and rotationally stiff, another local mode results and the longitudinal edge of each panel in this case is rotationally clamped giving rise to a higher buckling load for each sub-panel. Most ship panels must carry substantial lateral loads and this requirement usually produces stiffeners that are already larger and more rigid than the minimum sizes required by consideration of overall elastic buckling.

The degree of rotational restraints at the plate boundary is neither zero nor infinite, the former being equivalent to simply supported condition and the latter corresponding to fixed (or clamped) condition. The restraints at the plate boundary depend on torsional rigidity of support members which is neither zero nor infinity.

For practical design purpose with the benefit of mathematical simplicity, the simply supported boundary condition (i.e., with zero rotational restraints) is often adopted in maritime industry when analytical or semi-analytical methods are applied (Paik and Seo, 2009). In the present study simply supported boundary conditions has been applied on all four edges. Inplane compressive load has been applied on the finite element models of stiffened plates shown in Figure 8 and linear buckling analysis has been carried out. The first buckling mode for all the four stiffened plates simply supported on all four edges and subjected to an axial compressive load has been shown in Figure 9.

Table 4: Comparison of Critical Load for the Plates Stiffened with Four Different Types of Stiffeners

Sl No.	Stiffener Shape	Weight Ratio	Critical Load
			N/mm ²
1	Hat	1.00	261.35
2	Bar	1.36	100.8
3	Angle	1.01	265.01
4	Tee	1.03	277.32

The critical load for all the four stiffened plates has been presented in table 4. From the table it can be seen that the plate stiffened with flat bar has got a very low value for critical load. For plates stiffened with angle bar stiffeners and tee bar stiffeners the value of critical load is slightly higher as compared to hat stiffened plate but the variation is less than 6%.

Torsion Loading

A ship structure is subjected to torsion loads having two different origins, viz., still water torque and dynamic torque. Still water torque is created by uneven transverse distribution of weights, consumables or ballast. Dynamic torque is induced by the action of waves. Torsion due to a wave applied to a ship's structure like quartering sea causes a twisting of the structure about the longitudinal axis. To compare the structural response to torsion loading, the finite element models shown in Figure 8 has been used. All degrees of freedom on either ends of the stiffened panel have been arrested and a torsion load of 1 kN-m has been applied at the centre. The finite element model with applied load and boundary condition has been shown in Figure 10.

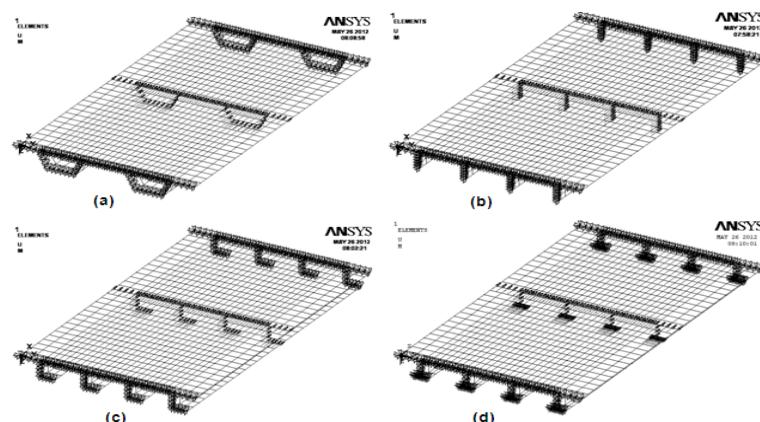


Figure 10: Finite Element Model with Applied Boundary Conditions and Torsion Load for Plate Stiffened with (a) Hat Stiffener, (b) Flat Bar, (c) Angle Bar and (d) Tee Bar

Warping stress, σ_x and the significant shear stresses obtained for all the four types of stiffeners have been given in table 5. It has been seen that warping stresses in the case of plates stiffened with angle stiffener and tee stiffeners are extremely high as compared to that for hat stiffened plate. Thus it has been seen that hat stiffened plate exhibits extremely superior weight strength efficiency when we compare the structural response to torsion load.

Table 5: Comparison of Warping Stress and Shear Stress for the Plates Stiffened with Four Different Types of Stiffeners and Subjected to a Torsion Load

Sl No.	Stiffener Shape	Weight Ratio	Warping Stress		Shear Stress in the Cross Sectional Plane	
			σ_x	Ratio	τ_{xy}	τ_{xz}
			N/mm ²		N/mm ²	N/mm ²
1	Hat	1	24.95	1	9.43	1.73
2	Bar	1.36	25.75	1.03	9.61	3.78
3	Angle	1.01	51.69	2.07	19.55	3.67
4	Tee	1.03	120.58	4.83	29.92	9.05

CONCLUSIONS AND RECOMMENDATIONS

The stiffened plates in a ship structure are subjected to lateral, inplane and torsion loading. The response of representative unit cell of hat stiffened plate and commonly used open section stiffeners to these types loading have been investigated. A comparison of weight, stress and deflection for hat stiffened plate and plates stiffened with open section stiffeners has been carried out and presented in table format. The comparison shows that hat stiffened plates exhibit better weight strength efficiency as compared to plates stiffened with commonly used open section stiffeners.

Hat stiffened plates can effectively be used as a substitute for commonly used open section stiffeners in ship building especially in the design of light weight steel ships. Presently hat stiffeners are used for stiffening the stool plates which support the corrugated bulkheads in bulk carriers. The hat stiffened plates can be used in the design of superstructure of a ship, where the chances of corrosion are less and the enclosed space between hat stiffener and the plate can be used as conduit for the electric cables. Hat stiffeners are also recommended for steel decks of Roll-on / Roll-off ships and also for hatch covers of bulk carriers and container ships. Usage of hat stiffeners will certainly result in lighter and hence more economical ships.

REFERENCES

1. Dubas, P, (1976), Plated Structure with Closed Section Stiffeners, Proceedings of symposium on Steel Plated Structures, Crosby Lockwood Staples, London, pg. 65.
2. D'Arcangelo, A, M, (1969), Ship Design and construction, SNAME, New York.
3. Jia, J, and Ulfvarson, A, (2004), Structural Behaviour of a High Tensile Steel Deck Using Trapezoidal Stiffeners and Dynamics of Vehicle – Deck Interactions, Marine Structures 18, 1-24.
4. Bediar, O, K, (1997), The elastic behavior of multi - stiffened plates under uniform compression, Thin Walled Structures, Vol. 27, pp. 311-335.
5. Paik, J, K, and Seo, J, K, (2009), Nonlinear Finite Element Method Models for Ultimate Strength Analysis of Steel Stiffened Plate Structures Under Combined Biaxial Compression and Lateral Pressure Actions - Part I: plate elements, Thin Walled Structures, 47, pp1008-1017.